

EFFECT OF VIBRATION AND LINEAR ACCELERATIONS ON FISH

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There are definite prospects for including fish in the closed cycle of matter. However, this presents problems to the research worker because the inclusion of a new link in the ecological system of the spacecraft requires a comprehensive study of this link, of its relationship to the other links in the process of metabolism, and the influence of extreme factors of space flight on it. /512

The inclusion of new groups of animals and plants in the closed cycle of matter on board the spacecraft calls for the study of the pattern of their reaction to the combination of extreme factors encountered during space flight.

The object of this investigation was to study the effect of vibration and linear overloads on fish in order to examine the influence of these extreme factors on them.

EXPERIMENTAL METHOD

Experiments were carried out on goldfish (*Carassius auratus gibelio* Bloch). The weight of the experimental fish varied from 49.65 to 131.3 g and their length from 16.0 to 21.0 cm. Before the experiment the fish were kept under aquarium conditions for the five months of autumn and winter. Before the experiments began the fish were carefully selected and tagged. The external appearance, movements and responses to stimuli of the selected fish were normal. Their body surface showed no signs of injury or disease. /513

Tests of vibration acceleration were carried out on the VEB-Geräte und Regeler Werke 20-1000 vibration bench. The fish were kept in an organic glass aquarium with a capacity of 9 liters. In experiments with vibrations in the frequency band 20-300 Hz the aquarium was tightly closed with a lid to prevent the water from spilling. In the experiments with frequencies above 300 Hz the aquarium was opened. In all the experiments water filled two-thirds of the total capacity of the aquarium, so that during vibrations waves were formed in the upper layers of the water (depending on the frequency and amplitude of the oscillations), and these exerted a definite additional influence on the fish if they came into the zone of these waves. Tests were carried out at the following frequencies: 20, 30, 50, 70, 80, 100, 300, 500, and 1000 Hz. In all the experiments vibration accelerations of about 10 units were created. At a given frequency of vibration such an acceleration was achieved by increasing the amplitude of the waves for 1-2 sec after the beginning of vibration.

The method mainly used to record behavior of the fish during exposure to vibrations was by taking motion pictures at a frame speed of 24/sec. The following cameras were used to take the pictures: "Rodina" ZKSKh, objective

75 mm; AKS-4, objective 50 mm. The object was illuminated by two KPL-35 projectors with a PZh-18 (5 kW) lamp. The filming program was as follows: a) to record the state of the fish before exposure to vibration pictures were taken for 15 sec; b) pictures were taken when the vibration bench was switched on and thereafter every 15 sec throughout the experiment. The working time of the camera in each filming period was 20 sec. Hence, during an experiment lasting 6 min, pictures were taken for 4 min; c) 10 min after switching off the vibration bench pictures were taken for 15 sec to record the aftereffects of vibration and also the initial stages of the period of recovery of normal behavior of the experimental fish.

Experiments in which the fish were exposed to linear overloads were performed on a centrifuge with maximal radius 500 mm.

The fish were kept in a hermetically sealed aquarium with capacity 4 liters, placed on a special mounting panel. The behavior of the fish during exposure to linear overloads was recorded on motion pictures taken with an AKS-2 camera, objective 35 mm. The object to be photographed was lit by two illuminators each fitted with 12 SM-15 lamps (2 V, 10 W). The camera, the aquarium with the fish, the mounting panel and the illuminators were all placed on the platform of the centrifuge. For close-up photography the transition ring for the objective was calculated and special conditions of photography worked out. In all experiments the fish was exposed to an overload not exceeding 20 units for various times, not exceeding 10 min. Tests were carried out in two variants: 1) overloading during acceleration of the centrifuge to the assigned speed followed by breaking to a complete halt; 2) prolonged exposure to overloading of between 2 and 10 min.

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The conditions of photography were chosen in accordance with these variants. The aquarium in which the experimental fish were placed was filled with water in two different ways: 1) to two-thirds of its capacity; 2) completely.

RESULTS AND DISCUSSION

When starting our study of the effect of vibrations on aquatic organisms we could find no references in the literature to the influence of this extreme factor on fish. Although the present investigations may be regarded as preliminarily, the very first experiments drew attention to certain aspects distinguishing the behavior of fish when exposed to vibrations of various frequencies. These were due primarily to the properties of the medium in which the fish lived relative to different vibrations. Water is, of course, a physical medium in which waves spread faster and further than in air. In this respect water resembles a solid body in its physical properties. Consequently, the effects of vibrations may be expected to be stronger on aquatic organisms than on terrestrial animals.

Whereas terrestrial animals experience the action of vibration from a vibrating surface with which they are in contact and the vibration overloading acts in the direction in which the surface vibrates, fish in a limited volume of water experience the effect of vibration in many directions. The floor, walls and lid (if present) of the aquarium all vibrate, and these vibrations are transmitted

by the column of water to the body of the fish in many directions. In addition, when water in an aquarium vibrates, static waves are formed on its surface, and if the fish comes into their zone it experiences additional effects from oscillation. Probably in the case of vibration of organisms in water it is impossible to speak of a strict direction of the vibration overload, more especially because the body of the fish is constantly changing its position relative to the vibrating walls of the tank. However, the principal direction from the source of vibrations and from that wall of the tank in contact with it is chosen. In our experiments vibration overloading acted on the body of the fish from below upward in a ventro-dorsal direction.

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Another feature to which our attention was directed before the experiments began was that fish possess a special organ receiving oscillations of different frequencies, and receiving oscillations of low frequencies from 5 to 30 Hz particularly well [2]. This is the lateral line organ with its numerous ramifications of nerves along the whole surface of the body of the fish. Consequently, rapid excitation of the nervous system of the fish and sharp changes in behavior may be expected in view of the direct effect of even weak vibrations on the lateral line receptor, and not merely through tactile receptors as in terrestrial animals. The third feature to which attention was drawn before the experiments is the completely unusual nature of the vibration as the stimulus for fish, although they are also unusual for other animals. For fish, which under natural conditions live in the quiet of deep waters and completely avoid sudden oscillations of water in any of its manifestations, vibrations of different frequencies and with considerable vibration overloads can be regarded as a powerful extreme factor. On these grounds we assumed that exposure of fish to the vibrations would have considerable consequences, and this was confirmed by the experiments.

Our assessment of the degree of action of vibrations on the fish was based on observations on the state of the following physiological function: a) movement of the gill covers (respiratory rhythm); b) general motor activity; and c) the balance reaction (changes in the position of the body of the fish relative to normal).

The experiments showed that vibrations of different frequencies, but with equal overloads (about 10 units) and acting for the same time (6 min) gave different effects on the fish. For instance, vibrations with frequencies within the range 20-40 Hz had an effect characterized by an increase in the frequency of respiratory movements, sometimes of considerable strength; an increase in motor activity from slight general movement to sudden and powerful swimming movements. During vibrations with frequencies of 20-40 Hz the fish began to dart to different sides of the aquarium as if avoiding the zone of vibration. No changes in the balanced reaction were observed.

Vibrations with frequencies of 50-70 Hz had quite the opposite effect on the fish from vibrations with frequencies of 20-40 Hz. The respiratory movements became slower, and arrhythmia was observed, varying from a slight degree to paroxysmal movements of the gill cover. In experiments with a frequency of 70 Hz, by the end of the third minute of action of vibration the respiratory movements became superficial, and often of "Cheyne-Stokes" type. The motor

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activity was affected just as in response to low frequencies. At the beginning of action of vibrations with frequencies of 50-70 Hz, a sharp decrease in motor activity was observed. The fish was in a "stunned" condition, falling to the bottom of the tank and remaining motionless for 2-3 min. The body of the fish listed slightly to the side, although the list was easily corrected during the first minutes of exposure to vibration. A further intensification of the vibration gave rise to a persistent disturbance of equilibrium. The fish turned over on its side and tried to restore the normal position of its body by sharp swimming movements (Figs. 1, a, b, c). Sometimes circular movements in a vertical plane with the fish on its side were observed. After discontinuing vibration the recovery period lasted about 1 h before the fish was normal again.

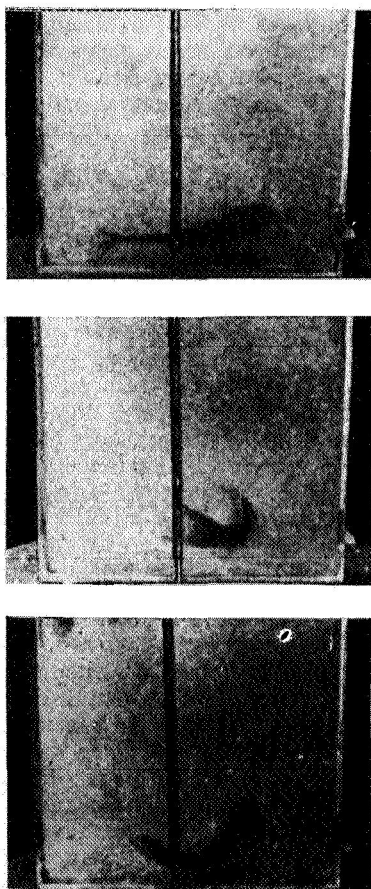


Figure 1. Action of Vibration (50-70 Hz) on Fish (a, b, c).

Frequencies of 80-90 Hz in our experiments have the strongest effect on the fish, sometimes lethal. Death was observed more than once 5-6 min after the beginning of vibration. Movements of the gill covers became very rapid and paroxysmal during the first minute of the experiment, and gradually changed into superficial and hardly visible movements. From being sharply increased initially, motor activity diminished until the fish were completely motionless. Only slight movements of the fins and tail were observed. Severe disturbances took place in the body equilibrium of the fish. From a strong list at the beginning of the experiment, they developed until the fish turned over onto its side, and after about 4 min of the experiment, it completely lost its balance. The body of the fish assumed any position in space, most frequently vertical, with its head down, and less frequently horizontal, on the floor of the aquarium with its ventral aspect upward (Fig. 2).

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With an increase in the frequency of vibration from 100 to 1000 Hz, the effect of vibration on the fish became less pronounced. The pattern observed in experiments with low frequencies (20-50 Hz) was repeated.

After the action of vibration was discontinued in the experiments, the pattern of recovery of the normal state of the fish differed. The investigated frequencies also differed sharply from one another. After vibrations with frequencies of 20-30 Hz, complete recovery of respiration and of normal swimming movements was observed within 10-15 min after the experiment. After the action of vibrations with frequencies of 50-70 Hz, the recovery period extended for



Figure 2. Action of Vibration (80-90 Hz) on Fish.

between 30 min and 1 h. After vibrations with frequencies of 80-90 Hz, recovery of the normal state was prolonged, lasting several hours, unless the fish died during the experiment. Sometimes, even after complete recovery had taken place and all external signs were normal, the fish died 1-2 days after the experiment.

In the character of the recovery period, the experiments with vibrations of frequencies between 100 and 1000 Hz were similar to those with frequencies of 20-50 Hz. For a rapid assessment of the degree of the general effects of vibration of the fish, we used a scale based on a six-point system.

Exposure to vibration of 0-3 points on our scale was tolerated perfectly satisfactorily by the fish. This vibration had no significant effect on the subsequent existence of the fish.

Vibrations of 4-5 points caused serious disturbance of the normal activity of the fish (disturbance of movement coordination, loss of balance, disturbance of respiratory movements of the gill covers, etc.). The fish tolerated exposure of this type badly, and although recovery of the normal condition of the fish according to external signs was observed, this does not rule out the possibility that the internal organs of the fish could have received injuries, the aftereffects of which will appear much later.

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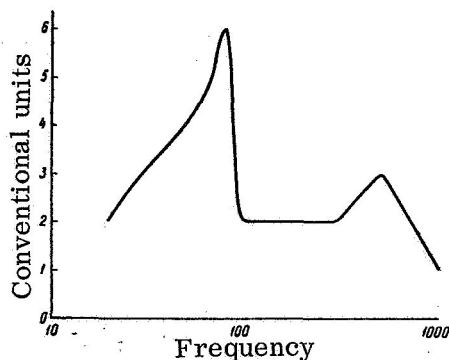


Figure 3. Frequency Characteristics of Action of Vibration on Fish.

Vibrations of six points proved lethal to the fish, and this assessment is made essentially after death of the fish either during the experiment or within 1-2 h thereafter.

Analysis of motion pictures of the experiment and of their written record shows that the degree of the effect of vibration on the fish varied with the frequency of vibration for equal overloads and equal times of action (Fig. 3).

Because of the sharp increase in the severity of the effects of vibration with frequencies of between 80 and 90 Hz, it seems possible that the resonance phenomena occur in this frequency band for fish 16-21 cm in length and 50-100 g in weight. This frequency band of vibrations is the most dangerous for fish of this species.

Scale for Assessing General Effects of Vibration on Fish

Severity of effect on fish	Points	State of physiological functions			Recovery period to normal after vibration
		Respiratory rhythm	Motor activity	Reaction of balance	
Absence of visible effect	0	Normal	Normal	Normal	
Very slight	1	Slightly increased	Slightly increased	Normal	5 min
Weak	2	Increased, sometimes greatly increased	Sharply increased	Normal	10 min
Moderate	3	Slowed	Decreased, "stunned"	Normal or slight listing	10-30 min
Strong	4	Arrhythmia, paroxysmal respiration	Sudden movements. Circular movements lying on side	Turning over on side, finds balance with considerable difficulty	1 hour
Very strong	5	Superficial respiration	Weak movements only of fins and tail	Complete loss of balance, body of fish assumes any position in space	Recovery within a few hours
Lethal	6	Respiratory movements absent	Movements absent	Complete loss of balance. After experiment fish lies on side on surface of water or on floor of tank	Death during first six minutes of experiment, sometimes a few days after experiment

As mentioned previously in the section "Experimental Method," we carried out experiments to study the effect of linear overloads caused by rotation on a centrifuge on the fish. It must be mentioned at once that these investigations were not intended for the purpose of determining limits of tolerance of the fish to linear acceleration. It is well known that organisms living in water tolerate linear overloads much better than organisms in an air environment. This is due primarily to the physical properties of the aquatic environment itself. Water considerably attenuates the action of acceleration on the body and the overload arising as a result. Because of the water surrounding the fish, the overload is uniformly distributed over the whole body, and the fish therefore does not experience local effects of overloading on different parts of its body. The limits of tolerance to overloads are thereby considerably increased. When studying this problem of tolerance to overloads by aquatic animals, Morris and Beischer [3] showed, for example, that small fish can withstand colossal accelerations of up to 10,000 g for 30 sec. Fish can withstand such unusually high overloads entirely because of the water surrounding their body. Resistance to considerable overloads has also been observed in aquatic invertebrates.

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We also set out to determine the character of the behavior of fish when exposed to linear overloads. In experiments on the centrifuge the fish were exposed to accelerations not exceeding 20 units, but were kept in aquaria filled with water up to different levels. In aquaria completely filled with water, after the first few seconds of rotation of the centrifuge and of increase of centrifugal force, the fish adopted a position so that the radial acceleration acted sideways, transversely to the body axis. It was noted that the fish arched its body in such cases to the side opposite to the action of the centrifugal force (Fig. 4).

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Figure 4. Action of Acceleration on Fish in a Completely Filled Aquarium.

Sometimes in these experiments the fish adopted a similar position of its body, but with its ventral aspect uppermost. This is probably because in the initial moments of increase of acceleration the fish makes sudden swimming movements, loses its balance, and adopts an incorrect position in space [4], fixing its body apparently in such a position that it can resist the increasing overload. During the action of overloads of 10-15 units or more, no movements of the gill covers whatsoever can be observed. It may be postulated that prolonged exposure to overloading essentially disturbs the breathing of the fish, although it may have suffered no other injury. In our experiments the normal rhythm

of respiration was restored 40-60 min after the procedure, but the normal body position and normal swimming movements were restored after 1-2 min.

The behavior of the fish was very unusual in experiments in which the aquarium was only half or two-thirds filled with water. In these experiments, as the centrifugal force increased the water was deflected toward the side wall



Figure 5. Action of Acceleration on Fish in an Aquarium Partly Filled with Water (a, b).

of the aquarium (the position of the meniscus was vertical). The fish was apparently thrown out of the water and found itself in the air, where it made sharp movements and tried to get back into the water (Figs. 5, a, b).

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This may be explained as follows: in our experiments we used a goldfish, the specific gravity of which according to data given by Yu.G. Aleyev [1], is 1.0-1.01; nevertheless, the presence of air in the swim bladder makes the central part of the fish's body lighter than water, and it is left behind when the water moves. This causes the body of the fish to curve into an arch in the experiments in which the aquarium is completely filled with water (Fig. 4). It may naturally be assumed that fish without a swim bladder, or with a very small bladder (whose specific gravity is much greater than that of water), cannot assume such a position.

The experiments to study the effects of linear overloads thus showed that the size of the air cushion in the aquarium is important for the fish.

If acceleration acts for a long time on a fish whose body has a specific gravity equal to that of water and large swim bladder, placed in an aquarium with a large air cushion, death of the fish may be hastened by its being thrown out of the water and being exposed to the action of acceleration in an environment of air, preventing the alleviating influence of the water surrounding the body of the fish.

Linear overloads of 20 units acting for a period of from 2 to 10 min are tolerated by fish with comparative ease. However, allowance must be made for the extent to which the vessel in which the fish is kept is filled with water, and for the specific gravities of the experimental fish.

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